

Astrobiology Technology Branch (SSR) Overview

The Astrobiology Technology Branch supports fundamental research and the development of advanced technologies in astrobiology as they relate to the exploration of space and understanding life in the universe. Current branch efforts encompass research and technology development for advanced life support, utilization of planetary resources, and astrobiology. Advanced Life Support focused research is directed primarily at physicochemical processes for use in regenerative life support systems required for future human missions and includes atmosphere revitalization, water recovery, waste processing/resource recovery, and systems modeling, analysis and controls associated with integrated subsystems operation. In-Situ Resource Utilization (ISRU) technologies will become increasingly important on every Mars lander between 2003 and a human mission to Mars. The branch focus is on the development of technologies for Mars atmosphere acquisition, buffer gas production, and CO₂ compression. Research and technology development for astrobiology includes understanding the physical and chemical limits to which life has adapted on Earth, the molecular adaptations that have allowed living systems to inhabit extreme environments, and the application of this knowledge to biotechnology, nanotechnology, and planetary protection. Researchers in the branch also develop flight experiments and associated hardware for shuttle, ISS, and unmanned NASA missions.

Mark H. Kliss

Chief, Astrobiology Technology Branch (SSR)

ADVANCED LIFE SUPPORT POWER REDUCTION

Cory K. Finn

This research involves modeling of the power and energy usage of regenerative life support systems suitable for exploring the Moon and Mars. System energy integration and energy reuse techniques are being investigated, along with advanced control methods for efficient distribution of power and thermal resources. The high power requirements associated with food production and overall closed regenerative system operation remain as a critical technological challenge. Optimization of individual processors alone will not be sufficient to produce an optimized system. System studies must be used in order to improve the overall efficiency of life support systems.

Designs are being developed that match sources of waste heat, such as crop lighting and solid waste processing systems, with processes that can use this waste heat, such as water processing, food processing, food preparation, and heating of shower water, dish wash water or clothes wash water. Using energy integration techniques, optimal system heat exchange designs are being developed by matching hot and cold streams according to specific design principles. For various designs, the potential savings for power, heating and cooling are being identified and quantified, and estimates are being made of the emplaced mass needed for energy exchange equipment.

Advanced control system designs are also being developed that allow for more efficient distribution of resources, such as system cooling water or electrical power, in order to reduce system power requirements. More efficient energy usage can be achieved by allocating power and thermal resources in a dynamic fashion. Advanced control techniques, such as market-based control, can be used in order to smooth out system thermal and power loads. Reductions in the peak loading will lead to lower overall requirements. The controller dynamically adjusts the use of system resources by the various subsystems and components in order to achieve the overall system goals. A typical system goal would be the smoothing of power usage and/or heat rejection profiles, while maintaining adequate reserves of food, water, oxygen, etc., and not allowing excessive build-up of waste materials. Initially, computer simulation models are being used to test various control system designs. The most promising of these will be tested using a laboratory-scale life support system testbed at Ames Research Center.

Energy balance models are being developed to support both the energy integration and the dynamic resource allocation work. These models leverage off of existing mass flow models of regenerative life support systems developed at Ames Research Center. The heat exchange designs and control schemes developed as part of this NRA research will be provided to Johnson Space Center for use in the development of the ALS Systems Integrated Test Bed (also known as BIO-Plex) and in the design of flight hardware for Moon or Mars missions.

Currently, energy integration techniques are being applied to the life support problem. Several potential designs that would be suitable for various Mars missions have been selected for application of the energy integration analysis. Life support data have been collected, and an optimized heat exchange design has been developed for each scenario. For each design, the potential savings in energy and cooling has been estimated.

In addition to the energy integration work, advanced control system designs are being developed that allow for more efficient distribution of electrical power. A dynamic model of the BIO-Plex air loop has been created and serves as a platform for the development of active power management strategies. Several resource allocation objectives have been defined and tested. One objective that was considered was to reallocate power as needed to the various life support processors to eliminate surges in power usage over time. However, the reallocation of power was subject to constraints. For example, material storage levels needed to be maintained, as well as atmospheric conditions within the life support chambers. This power management system has been demonstrated using the simulation model and performed reasonably well. A second objective that has been and continues to be investigated is to smooth the demand for power throughout the system over time. \Box

SOLID-STATE COMPRESSOR FOR SPACE STATION OXYGEN RECOVERY

John Finn

At present, the life support system on the International Space Station Alpha vents overboard the carbon dioxide produced by the crew members. Recovering the oxygen contained in the CO_2 has the potential to reduce resupply mass by 2000 pounds per year or more, a significant weight which might instead be used for experiment payloads and other valuable items. The technologies used to remove CO_2 from air and to recover O_2 from CO_2 are flight-ready. However, the interface between the devices is a problem for the Space Station system. NASA Ames has developed a new technology that solves the interface issue, possibly allowing for the first time closure of the oxygen loop in a spacecraft.

The relevant part of the air revitalization system is shown in Figure 8. CO_2 produced by the crew is removed in the Carbon Dioxide Removal Assembly, or CDRA. This device effectively produces a pure CO_2 stream, but at a very low pressure. Elsewhere the oxygen generation system, which makes O_2 by electrolyzing water, produces a hydrogen stream. In principle the CO_2 and H_2 can react to form methane (CH_4) and water (H_2O) over a suitable catalyst. Water produced in this methane-formation reactor can be returned to the water electrolyzer, where the O_2 can be returned to the cabin. However, the methane-formation reactor requires CO_2 at a much higher pressure than that produced by the CDRA. Furthermore, the CO_2 and H_2 are often not available at the same time, due to power management and scheduling on the space station. In order to get the CO_2 to the reactor at the right pressure and at the right time, a device or assembly that functions as a vacuum pump, compressor, and storage tank is required.

One obvious solution to this problem is to use a mechanical vacuum pump/compressor combined with a high-pressure buffer tank. This has implementation problems, however. The rapidly moving parts of a mechanical compressor wear out relatively quickly, requiring frequent maintenance or replacement. The mechanical compressor can add noise and vibration to the sensitive station environment, unless large amounts of insulating material is provided. There is so little space available for the buffer tank that the compression ratio would have to be quite high. Finally the power required to compress the CO_2 to high pressure is considered very high for the power-limited Space Station.

The solution being developed by NASA Ames engineers uses a technique they originally developed for compressing the very low pressure Mars atmosphere so that it could be used in an in situ propellant production plant. The compressor uses a temperature-swing adsorption cycle and has no rapidly moving parts. Low-pressure CO_2 from the CDRA is adsorbed in a cool cylinder containing a sorbent material that has a high capacity for CO_2 . In this step, the device acts like a vacuum pump. Next, the cylinder stays in a standby mode until the CO_2 is required; i.e., the device acts like a storage tank. Finally, the cylinder is heated and the CO_2 is driven off the sorbent, producing CO_2 at a high pressure. The compressed CO_2 flows into the methane-formation reactor. Coolant from the Space Station's thermal control system cools the cylinder back to its initial state, and the process is repeated. Several such cylinders are combined in the device. They operate out of phase from each other, so that there is always a "vacuum pump" and a "compressor" available whenever they are needed by the processors on either side.

A single-bed prototype solid-state compressor was built at Ames and successfully tested with a high-fidelity CDRA at NASA Marshall Space Flight Center in 2000 (Figure 9). The temperature-swing adsorption compressor uses much less power than the mechanical compressor system and has far fewer parts. Its lifetime is estimated at ten years. It is free of vibration and noise, and is also smaller and lighter than its counterpart. \square

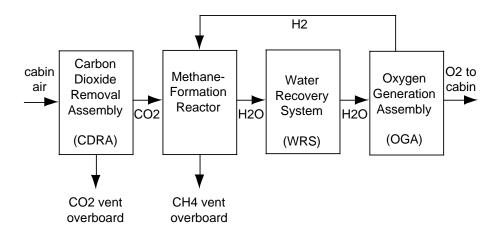


Figure 8: Carbon dioxide removal, carbon dioxide reduction, and oxygen generation planned for the International Space Station (methane-formation is not yet implemented). The compressor would be placed between the carbon dioxide removal and methane-formation reactor assemblies.

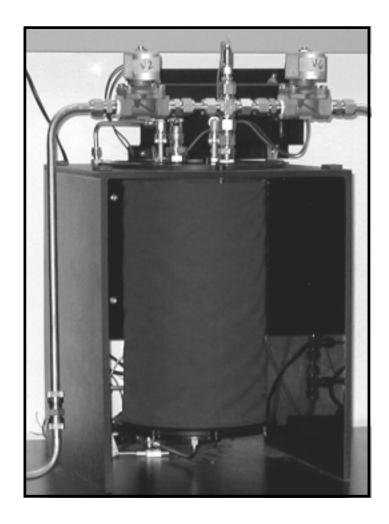


Figure 9: Single-bed prototype of a NASA Ames solid-state compressor.

DEVELOPMENT OF A WASTE PROCESSING INCINERATOR FOR LIFE SUPPORT

John W. Fisher

As space missions become longer, waste treatment on a space craft transitions from storage to reclamation of items such as activated carbon and carbon dioxide. Activated carbon and carbon dioxide can be reclaimed from hydrocarbon wastes such as paper, food scraps, and inedible plant biomass. Inedible plant biomass is produced when plants are grown in space to produce food. Growing plants consume carbon dioxide, and burning the inedible parts of a plant produces carbon dioxide that can be used to grow more plants. Unfortunately the process of burning, combustion, produces some toxic byproducts. One of the objectives of Ames' research on waste processing is to develop technology to burn waste and reclaim carbon dioxide without releasing toxic materials into the spacecraft.

The combustion process generally does well at completely oxidizing biomass to carbon dioxide and water. This is obvious from observation of the results of a typical wood fire. Only a small residue of inorganic substances, ash, is left in a fireplace after burning wood. The process of combustion of biomass in an incinerator operates in a similar way; the biomass is converted to gaseous products and inorganic ash. However, combustion in a fireplace typically takes place with wide fluctuations in temperature and composition as a function of time and position in the burning zone. Efficient combustors reduce the combustion fluctuation and achieve cleaner burning.

Fluidized combustion is a technology that provides good control of the combustion process and minimizes contaminants due to incomplete combustion. A fluidized bed consists of a bed of solid particles such as sand that behaves as a fluid. The fluidization occurs because a gas such as air is blowing up through the bed and causing the particles of the bed to float. Because sand is much denser than air, the bed holds much more heat energy than an equivalent amount of air. The heat energy held by the bed buffers the combustion process against the wide fluctuations in temperature that cause incomplete combustion.

Even in the best of combustors, however, some unoxidized material remains. In addition, some contaminants such as nitrogen and sulfur oxides are necessarily formed. In recent years Ames' research has focused on means to eliminate these byproducts. One approach has been to use reductive catalytic systems to convert the nitrogen and sulfur oxides to nitrogen and elemental sulfur – innocuous materials at room temperature. Oxidative catalysts can then oxidize the remaining hydrocarbon contaminants to very low levels.

In collaboration with outside university and corporate organizations Ames has developed and tested an integrated incineration system that utilizes a fluidized bed combustor followed by a catalytic cleanup system. This system has demonstrated the ability to burn inedible biomass and produce a very clean carbon dioxide product. The concentration of contaminants in the gas exiting the incinerator is generally less than a few parts per million. Except for the carbon dioxide itself (toxic to humans at high concentrations), the exit stream from the incinerator will be able to meet the Space Maximum Allowable Contaminant (SMAC) standards for clean air in a spacecraft.

When this system has been optimized for reliability and energy efficiency, it will be ready for testing in an advanced life support system that "closes the loop" on carbon. Carbon will travel in the system from plant to person to incinerator and back to the plant without ever becoming a stored waste. \Box

DEVELOPMENT OF THE VAPOR PHASE CATALYTIC AMMONIA REMOVAL PROCESS

Michael Flynn and Bruce Borchers

The Vapor Phase Catalytic Ammonia Removal (VPCAR) system technology represents the next generation in space flight water recovery systems. Water is the single largest resupply requirement associated with human space flight, accounting for 87% by mass of an astronaut's daily metabolic requirement. The VPCAR system achieves a mass metric almost an order of magnitude better than the current state of the art water processors. (Mass metric is a technique used to compare candidate technologies by reducing all performance parameters into a single equivalent launch mass metric.) Incorporating the VPCAR technology into human space flight missions could potentially save hundreds of millions of dollars in resupply costs, depending on the specific mission scenario. As a result, a human-rated version of the VPCAR technology has been authorized for development.

The human-rated system is being developed under contract to Water Reuse Technology (NAS2-00089). This is an external contract for the development and testing of the next generation VPCAR technology. We are currently about 1/2 way through a two year contracted development program. This activity is funded through Advanced Life Support program funds and a NASA peer reviewed NRA (00-HEDS-01)

Process Description

The VPCAR process is a two-step distillation based water processor. The current configuration of the technology is shown in Figure 10. A process flow diagram is provided in Figure 11. The VPCAR process is characterized by the use of a wiped-film rotating-disk (WFRD) vacuum evaporator to volatilize water, small molecular weight organics, and ammonia. This vapor stream is then oxidized in a vapor phase catalytic reactor to destroy any contaminants. The VPCAR process uses two catalytic beds to oxidize contaminants and decompose any nitrous oxide produced in the first bed. The first catalytic bed oxidizes organics to carbon dioxide and water, and ammonia to nitrous oxide and water. This oxidation reactor contains 1% platinum on alumina pellets and operates at about 523 K. The second catalytic bed reduces the nitrous oxide to nitrogen and oxygen. This reduction catalyst contains 0.5% ruthenium on alumina pellets and operates at about 723 K. The reactor and distillation functions occur in a single modular process step. The process achieves between 97-98% water recovery and has no scheduled maintenance or resupply requirements for a minimum of three years.

The VPCAR activity is significant in that it represents the development of the next generation of life support water recovery technology. Ames Research Center's involvement has spanned from the first principle definition to the model development, bench-scale and lab-scale prototype development, and most recently, contract management of the development of a human-rated version of the technology for evaluation for space flight application. \Box



Figure 10: Vapor Phase Catalytic Ammonia Removal (VPCAR) water recycling system.

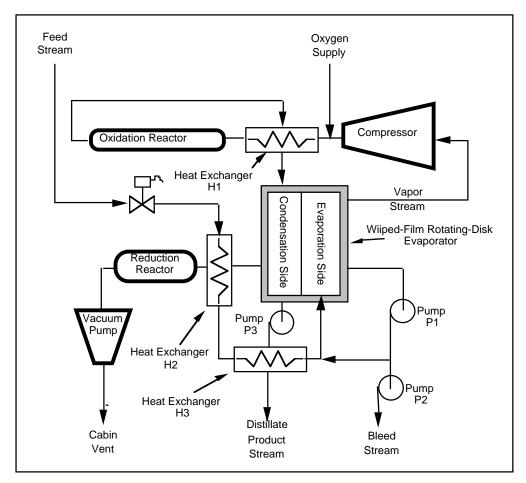


Figure 11: VPCAR Flow Diagram

PROTEIN NANOTECHNOLOGY

Jonathan Trent

In support of NASA's efforts to make missions "faster, better, and cheaper" there is a growing need for the development of smaller, stronger, and 'smarter' scientific probes compatible with space exploration. The necessary breakthroughs in this area may well be achieved in the revolutionary field of nanotechnology. This is technology on the scale of molecules, which holds the promise of creating devices smaller and more efficient than anything currently available. While a great deal of exciting research is developing around carbon nanotubes-based nanotechnology, we at NASA Ames Research Center are also exploring biologically inspired nanotechnology.

The biological 'unit,' the living cell, may be considered the ultimate nano-scale device. Cells, which are constructed of nano-scale components, are extremely sensitive, highly efficient environmental sensors capable of rapid self-assembly, flawless self-repair, and adaptive self improvement; not to mention their potential for nearly unlimited self-replicate. Ames is focusing on a major component of all cells (proteins) that are capable of self-assembling into highly ordered structures. A protein known as HSP60 is currently being studied that spontaneously forms nano-scale ring structures (Figure 12A, end view; B, side view), which can be induced to form chains (Figure 12C) or filaments (Figure 12D).

By using thermostable HSP60s, highly efficient methods have been developed for purifying large quantities of these proteins and by using the 'tools' of molecular biology, their composition and structure-forming capabilities are being currently modified.

For example, by removing a small fragment of the HSP60 protein, protein rings are produced that do not form chains or filaments, but continue to form rings that spontaneously assemble into highly ordered hexagonally-packed arrays (Figure 13A).

By further modifying each of these proteins so they bind metal atoms, these proteins can be used as a template to create an ordered pattern of metal on a surface with nanometer spacing. Ultimately the hope is to use such ordered arrays of metal to manufacture nano-scale electronic devices. Similarly, metal binding to proteins that form filaments (Figure 13B) may be used to create self-assembling nano-scale wires, which may someday be used to produce self-assembling circuits.

There are many potential applications for protein-based nanotechnology applicable to the production of smaller, stronger, and 'smarter' probes for NASA or more generally for applications in electronics and medicine. The combination of nanotechnology, information technology, and biotechnology at NASA Ames Research Center provides an excellent research environment for biologically-inspired nanotechnology. Analytical capabilities in nanotechnology provide essential tools for determining structure and function of protein-based systems. Supercomputing in information sciences provide capabilities essential for molecular simulations and biomolecule visualizations. Biotechn ology

provides the methodological basis for the genetic engineering essential for modifying and functionalizing protein structures. The goal is to establish the feasibility of creating useful protein-based nanostructures with applications for NASA and other critical areas of technology. \Box

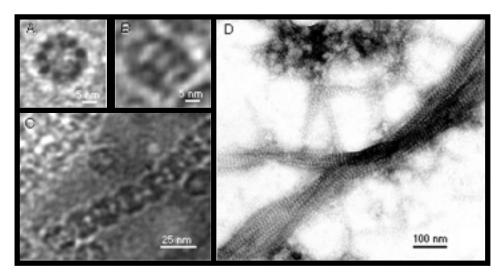


Figure 12: Protein rings (A end view, and B side view), chains of rings (C), and bundles of chains (D) that can be used in nanotechnology.

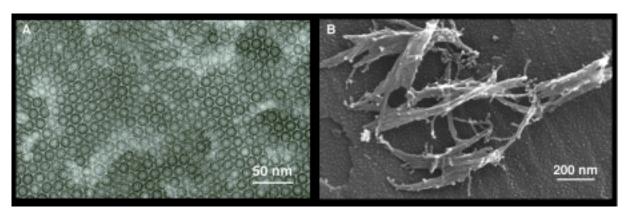


Figure 13: Modified proteins form hexagonally packed rings (A) or metal-containing protein filaments (B).